SAM-TR-68-108

BATCH-FEEDING STUDIES ON HIGH-SOLIDS ACTIVATED SLUDGE FOR TREATING CONCENTRATED HUMAN WASTE

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September 1968

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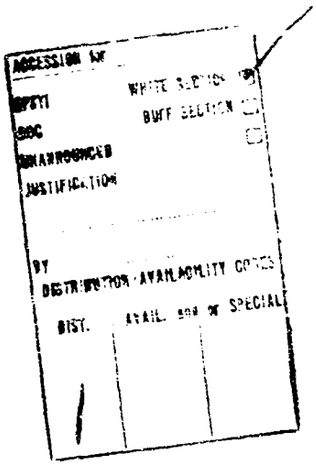

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FOREWORD

The research described in this report was conducted by the Environmental Systems Branch under task No. 793001. The work was accomplished between January and June 1967. The report was received for publication on 9 July 1968.

This report has been reviewed and is approved.

GEORGE E. SCHAFER
Colonel, USAF, MC
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ABSTRACT

As part of a continuing Air Force research effort toward the development of a biologic waste management system for closed environments, studies were conducted on a miniaturized activated sludge process for treating concentrated human wastes. During a 40-day continuous run, a prototype sludge reactor was fed batchwise (daily) with an increasing quantity of mixed human waste. Removal of chemical oxygen demand (COD) and the quality of the clarified process effluent were monitored as functions of time and the feeding rate. Results showed that the activated sludge culture could be acclimated to handle highly concentrated human excreta with little dilution. At a loading rate of 5.0 gm. COD/liter of culture, approximately 80% of the feed COD was removed after 23 hours of processing. Both the capacity for COD removal and the quality of the process effluent were found to be strong functions of the air supply rate. Recommendations were made regarding the use of a continuous feed system for better optimization of the uptake rate.

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I. INTRODUCTION

The high-solids activated sludge process has attracted great interest as a means of stabilizing concentrated human waste products. For application in sealed environments, the sludge process is preferred to other waste treatment systems—for example, oxidation ponds, bacterial beds, or anaerobic digestion—because of its inherently higher rates of oxidation and more desirable metabolic end products (1, 2). In recent years the Air Force has pursued a research program to characterize the sludge process and to examine its total capabilities. Studies have been conducted on the detailed microbiology of activated sludge (3, 4) a ' on technics and hardware for utilization ot the process in closed-system waste treatment (5).

Activated sludge is composed of a broad spectrum of microbial forms which are produced within the waste mixture, and which attack and stabilize a wide range of organic materials. The process is kept aerobic by forced aeration. Stabilization occurs from the fact that the microorganisms utilize the wastes as a food source in their metabolism which comprises the processes of both anabolism and catabolism. Anabolism includes the assimilative reactions leading to new cellular biomass, while catabolism results in the breakdown of protoplasm into such molecular constituents as carbon dioxide, ammonia, and water. The types and relative numbers of microbial flora present are determined by the nature and concentration of the waste feed, as well as by such environmental factors as temperature and aeration. Some of the more common bacteria present are of the genera *Achromobacterium*, *Chromobacterium*, *Flavobacterium*, and *Pseudomonas* (8). There also exist large numbers of Protozoa and Metazoa in ecobalance with the bacteria.

The activated sludge process has been employed for a number of years in municipal and industrial sewage treatment plants, and a wealth of data is available for large-scale applications of this type. However, little of this information is applicable to the design and development of aerobic waste treatment systems in closed environments because of the greater loading rates encountered and the correspondingly greater microbial populations and qualitative differences. Conventional (municipal) activated sludge units are generally loaded at the rate of 0.5 to 1.0 gm. of chemical oxygen demand (COD) per liter of aerated tank capacity. In a closed environment such as a space capsule, t'. ' waste treatment system must accommodate a feed rate of 3 to 6 gm. COD liter in order to minimize the system volume and weight. Hence, studies were undertaken to define the characteristics of the miniaturized, high-solids activated sludge process. Following the development of a prototype sludge reactor (5), we began experiments on the effects of major process variables on long-term performance of high-solids activated sludge. This report describes a 40-day continuous run with a prototype bench-scale reactor using a batch-feed regimen.

II. METHODS AND MATERIALS

Description of the waste treatment unit

The activated sludge waste treatment unit used in this work was designed and fabricated

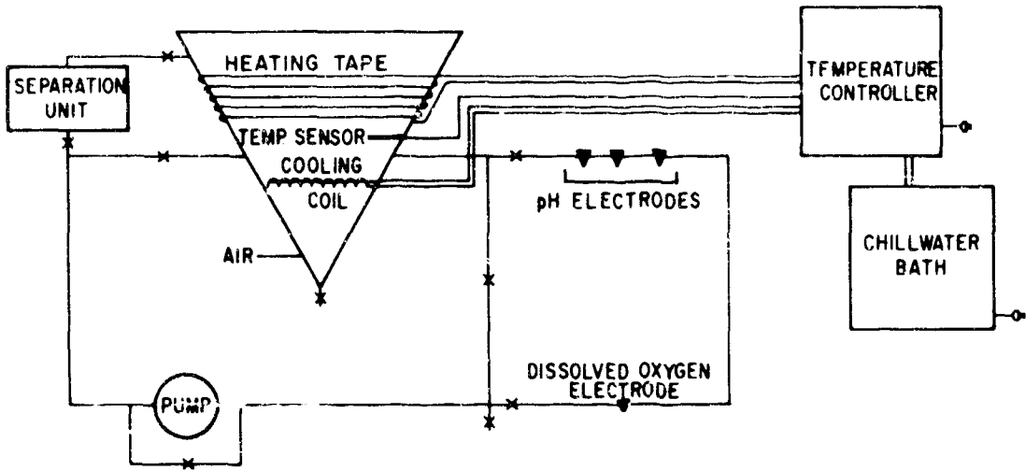


FIGURE 1

Schematic of the activated sludge waste treatment process.

by Chapman et al. (5). The system was originally sized to accommodate the urine and feces of one man per day—that is, a volume of about 2.5 liters/day of human excretory waste having a total carbon concentration of about 20 gm./liter as COD. In configuration and selection of construction materials, the unit was designed as a research tool to obtain data on the continuous operation of the sludge process.

Figure 1 shows an operational schematic of the activated sludge system. The apparatus had a gross liquid capacity of 14 liters. For this study a culture volume of 10 liters was employed to allow adequate freeboard and to permit greater loading rates (gm. COD/liter). The culture vessel consisted of an upright cone, 30 cm. in diameter at the top and 60 cm. in height. The cone-shaped section was selected to permit thorough aeration and mixing of the culture in the reactor. The mixed liquor was continuously recirculated from the reactor through an analysis loop back to the cone. The analysis loop contained electrodes for measuring pH and dissolved oxygen (DO). Oxygen was supplied to the culture by the dispersion of air injected at the bottom of the cone. The product gases were exhausted through an exit port (3 cm. diameter) located in the side wall of the cone immediately under the reactor cover.

The reactor system was fabricated so that all pumps, valves, and piping in contact with the culture were either stainless steel, polyvinyl chloride (PVC), or polypropylene plastic. The reactor cone was constructed of 316 stainless steel. The analysis loop consisted of PVC pipe (1_2 inch) and Tygon tubing sections which served as flexible couplings. PVC and polypropylene ball valves were used to isolate portions of the flow system and to permit drainage. The circulating pump was a reversible, positive-displacement, plastic-impeller type (Jabsco model P-6-M6), with a capacity of 20 liters/min.

Culture temperature was measured by a resistance sensor located in the center of the reactor. Temperature was controlled by a relay-controller (YSI model 73) which alternately permitted addition or removal of heat. Heat was added by means of a heating tape around the cone, and removed by means of a cooling coil located in the bottom of the reactor.

The separation unit for withdrawing effluent was a continuous microfiltration device

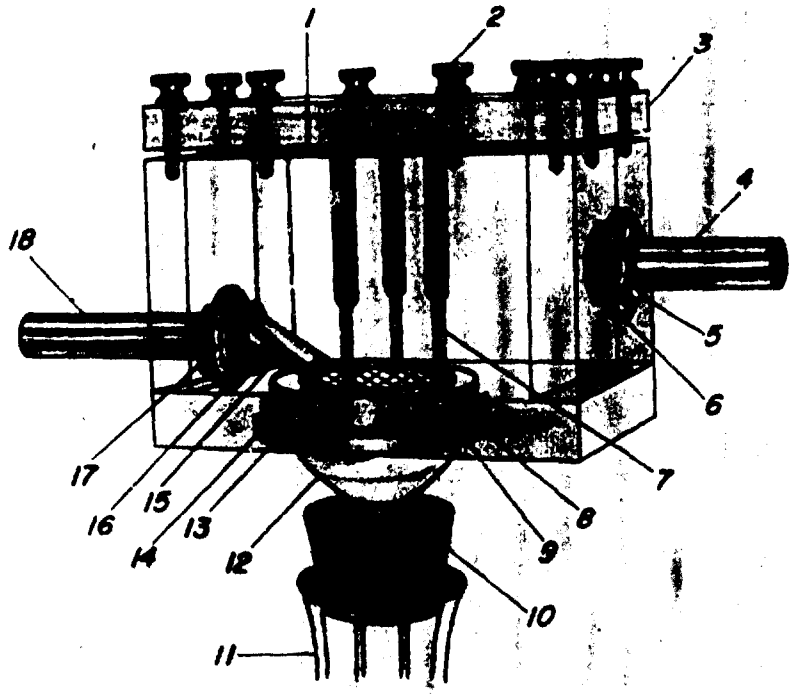


FIGURE 2

View of the continuous solids-liquid separation device used for this study.

developed by Ryan (11). Figure 2 shows a schematic of the apparatus which consisted of a microporous filter contained in a Plexiglas box with entrance and exit ports for circulating the mixed liquor suspension. By use of 0.45 μ filters (Millipore type HA), 100 to 150 ml./hr. of clarified effluent could be removed continuously. All particles larger than 0.45 μ in diameter were retained in the system. In an earlier configuration, the waste treatment system was equipped with a leaf-type filter for separating the biologic floc from the mixed liquor (6). Floc separation required the addition of a coagulant-forming electrolyte (Dow C-32) to assist in forming large floc particles which were retained on a mesh plastic filter. The procedure required pumping the culture slowly through the leaf filter box to maintain a head differential across the filter of less than 5 cm. of water. In preliminary trials, this technic proved unsatisfactory and gave effluent of poor quality, owing primarily to the fragility of the floc which readily broke up and passed through the filter into the collection flasks. For this reason, the microfiltration apparatus was developed and used throughout this study.

Waste feed

The waste feed used for this study was a mixture of human urine and feces approximating that expected from man in a closed environment. The urine and feces were collected separately from male volunteers and refrigerated. The standard feed mixture was prepared by combining the individual wastes from each volunteer in the ratio of 200 ml. feces to 1,800 ml. urine to 500 ml. of tap water. The individual mixtures were thoroughly mixed in a Waring blender and analyzed for BOD (biological oxygen demand), pH, nitrate, nitrite, ammonia, and phosphate to establish the range of these parameters shown in table I. The standard waste feed was obtained by pooling equal quantities (200 ml.) of the individual waste mixtures. Analysis of the standard feed is given in table I as the "average" composition. The COD of the standard feed mixture was 20 gm./liter.

TABLE I

Values for human waste samples

Parameter	Range	Average value
COD (mg./liter)	—	20,000
BOD (mg./liter)	12,500 to 15,000	14,300
pH	8.0 to 8.7	8.5
NO_2^- (mg./liter)	0 to 2	0
NO_3^- (mg./liter)	0 to 2	1
NH_4^+ (mg./liter)	1,500 to 4,500	3,000
PO_4^- (mg./liter)	1,800 to 2,500	2,200

Experimental design

Feeding protocol. The levels of fresh feed charged to the reactor were preselected and increased in even increments from 5 to 50 gm./day. Since the total culture volume was maintained at 10 liters, the concentration of fresh-feed COD at the time of charge was increased stepwise from 0.5 to 5.0 gm./liter, respectively. Table II shows the daily feeding schedule and loading conditions.

The unit was fed each day by placing the programmed amount of waste feed directly, in bulk, into the culture vessel. Samples were drawn from the culture before feeding for determination of suspended solids, and at hourly intervals after feeding for determination of supernatant COD. Before feeding on the following day, a volume of effluent was recovered corresponding to the volume of feed programmed for addition. This protocol gave a detention time of 23 hours for the wastes in the reactor since about one hour was needed to recover the effluent.

The seed culture for the experiment was obtained from the secondary settling basin of the San Antonio Rilling Road wastewater treatment plant. For one day prior to the start of the experiment 5 liters of seed culture was aerated in the unit with 5 liters of raw settled sewage as substrate.

Aeration. Two aeration rates were employed at each feeding level to determine the effect of dissolved oxygen at limiting and nonlimiting concentrations. The high (nonlimiting) air rate exceeded the calculated oxygen requirement for the feeding level and provided air at the rate of 36 liters/hr. per gram of fresh-feed COD. The low (limiting) air rate was less than the calculated requirement at each feed rate and provided 3.6 liters/hr. per gram COD at the lower feeding levels, gradually increasing to 4.8 at the highest feeding level. The air rates employed at each feeding level are shown in table II.

Temperature. The culture temperature was maintained at 32 ± 1° C. throughout the run. Chapman et al. (3) have reported two activity peaks for activated sludge cultures, one at 32° C. and the other at 65° C. The growth constant reported for the 65° C. culture was, however, slightly less than that reported for the 32° C. culture. Hence, the lower temperature was chosen for this study.

Analyses. The parameters used to evaluate the quality of the effluent were selected for the twofold purpose of examining the effectiveness of the treatment process and determining the acceptability of the effluent as a plant substrate medium. To satisfy these objectives, the following analyses were run: COD, BOD, suspended solids, pH, nitrate, nitrite, ammonia-nitrogen, and phosphate. All assays were performed in accordance with *Standard Methods for the Examination of Water and Wastewater* (13).

III. RESULTS

Culture growth

Throughout the run, growth of the sludge culture was continuous and roughly proportional to the feeding level. Noteworthy was the fact that the culture readily adapted to the high feeding levels with no evidence of metabolic inhibition or toxicity. The growth rate of the culture as measured by increase in suspended solids is indicated in table II. Over the 40-day period of the run, the total solids concentration increased from 0.62 to 35 gm/liter.

TABLE II

Daily log of feed rates and processing conditions

Day	Biomass before feeding (gm./liter)	Fresh feed added (volume, liters)	Fresh feed added (COD, gm.)	Total initial COD* (gm./liter)	Loading ratio (gm. COD/ gm. biomass)	Air rate (liters/min.)	Before-feeding pH	After-feeding pH
0	0.621	0.25	5	0.5	0.81	3	6.7	6.6
1	1.19	0.25	5	0.5273	0.44	3	6.8	6.9
2	1.98	0.25	5	0.534	0.27	0.3	6.8	6.9
3	2.75	0.50	10	1.437	0.52	6	7.3	7.2
4	3.22	0.50	10	1.030	0.32	6	7.1	7.1
5	5.21	0.50	10	1.022	0.20	0.6	7.0	6.9
6	7.50	0.75	15	1.875	0.25	9	7.4	7.4
7	8.74	0.75	15	1.640	0.19	9	7.2	7.3
8	9.40	0.75	15	1.778	0.19	0.9	7.3	7.2
9	9.02	1.00	20	2.702	0.30	12	7.6	7.6
10	11.09	1.00	20	2.541	0.23	12	7.0	7.1
11	13.40	1.00	20	2.440	0.18	12	6.9	7.2
12	15.05	1.00	20	2.453	0.16	1.2	7.1	7.2
13	14.90	1.25	25	3.358	0.23	15	7.6	7.7
14	17.00	1.25	25	3.279	0.19	15	7.4	7.5
15	18.54	1.25	25	3.209	0.17	15	7.3	7.3
16	19.20	1.25	25	3.20	0.17	1.5	7.3	7.4
17	18.90	1.50	30	4.232	0.22	18	7.8	7.9
18	22.80	1.50	30	4.02	0.18	18	7.4	7.6
19	24.30	1.50	30	3.867	0.16	18	7.3	7.4
20	24.40	1.50	30	4.028	0.16	18	7.5	7.4
21	24.20	1.50	30	4.105	0.17	2.0	7.3	7.3
22	24.30	1.75	35	5.068	0.22	21	8.0	8.1
23	23.10	1.75	35	4.894	0.21	21	7.5	7.4
24	28.60	1.75	35	4.853	0.17	21	7.6	7.5
25	29.10	1.75	35	4.936	0.17	2.5	7.4	7.4
26	29.00	2.00	40	5.224	0.18	24	7.9	7.9
27	29.25	2.00	40	5.744	0.20	24	7.8	7.9
28	30.50	2.00	40	5.544	0.18	24	7.9	7.9
29	31.60	2.00	40	5.640	0.18	24	7.6	7.7
30	33.00	2.00	40	5.608	0.17	3.0	7.7	7.8
31	32.95	2.25	45	6.840	0.21	27	8.3	8.3
32	35.45	2.25	45	6.693	0.19	27	8.0	8.1
33	34.10	2.25	45	6.445	0.19	27	7.9	7.8
34	35.40	2.25	45	6.507	0.18	27	7.8	7.8
35	35.70	2.25	45	6.546	0.18	3.5	7.7	7.8
36	35.02	2.50	50	8.098	0.23	30	8.6	8.7
37	35.50	2.50	50	8.780	0.25	30	8.5	8.5
38	35.50	2.50	50	8.060	0.23	30	8.6	8.7
39	35.10	2.50	50	7.992	0.23	30	8.7	8.8
40	35.09	2.50	50	8.375	0.24	4.0	8.9	8.6

*Fresh feed plus residual.

TABLE III

Effluent quality after 23 hours' processing

Day	Volume recovered (liters)	pH	COD	BOD	Nitrate	Nitrite	Ammonia nitrogen	Phosphate
					(mg./liter)			
0	0.25	6.8	28					
1	0.25	6.7	35	25	4	0	1	20
2	0.50	7.2	460		1	1	3	15
3	0.50	7.0	32					
4	0.50	7.0	23	20	1	1	1	27
5	0.75	7.4	405		1	1.5	5	33
6	0.75	7.1	151					
7	0.75	7.2	301	150	12.8	1	13	45
8	1.0	7.6	780		3.7	2.4	22	40
9	1.0	7.2	601					
10	1.0	7.0	489					
11	1.0	7.0	503	330	0.3	0	28	90
12	1.25	7.3	980		7.6	2.9	75	105
13	1.25	7.4	890					
14	1.25	7.3	810					
15	1.25	7.2	800	530	18.6	1	53	160
16	1.50	7.5	1,450		9.2	3.6	110	150
17	1.50	7.6	1,200					
18	1.50	7.4	1,020					
19	1.50	7.5	1,210					
20	1.50	7.3	1,300	960	21.5	1	125	190
21	1.75	7.8	1,900		13.1	5.3	230	220
22	1.75	7.7	1,690					
23	1.75	7.6	1,640					
24	1.75	7.6	1,740	1,190	32.7	1	213	410
25	2.0	7.8	2,780		20.2	11.1	420	380
26	2.0	7.8	2,180					
27	2.0	7.9	1,930					
28	2.0	7.5	2,050					
29	2.0	7.6	2,010	1,410	20.1	0	205	910
30	2.25	8.2	3,020		12.3	19.3	500	905
31	2.25	7.9	2,830					
32	2.25	7.9	2,510					
33	2.25	7.9	2,590					
34	2.25	7.4	2,640	1,850	78.7	2	620	1,410
35	2.50	8.3	4,130		18.6	30.2	950	1,390
36	2.50	8.4	5,040					
37	2.50	8.4	4,080					
38	2.50	8.6	3,9 0					
39	2.50	8.6	4,500	3,800	98	2	1,200	1,700
40	2.50	8.7	6,020		20.2	52	1,730	1,710

Gross microscopic examination of the culture revealed that the bacterial flocs became smaller and more filamentous in nature as the feeding level increased. Ciliates and rotifers were the predominant animal forms, although an occasional zooflagellate was noted. After the daily feeding, an increase in bacterial forms was apparent, followed by a subsequent increase in free-swimming ciliates and zooflagellates. After about 20 hours of aerated digestion, stalked ciliates and rotifers predominated, and were observed feeding on the bacterial flocs present. This pattern was followed throughout the run and the numbers of the various animals increased in approximately the same proportion.

COD reduction

Reduction in the COD of the fresh feed was examined from two standpoints. One was to determine the capacity of the sludge culture to stabilize concentrated waste in a 23-hour detention period. The second was to determine the rate of COD removal to obtain insight into the mechanism of substrate uptake by the organisms.

Table III gives the quality of the effluent produced after 23 hours of processing. As expected, the effluent COD increased steadily with increasing feed at both the high and low air rates. From the nature of the experimental protocol, this increase was a result of two contributions—the increasing COD of the feed, and the increasing COD of the residual volume in the reactor to which the feed was added each day. This second contribution represented that portion of the feed which was less readily assimilated. Hence, as the run progressed, the total COD charge at the start of each reaction period consisted of an increasingly larger fraction of refractory material. The effect of this buildup was most evident in the data for the 5.0 gm. COD liter feed level which was also the last. At this feed rate, the total COD load was approximately 8.0 gm. liter and the effluent COD after 23 hours of high aeration was 4.5 gm. liter. Hence the undigested COD was 56% of the total load but only 22.5% of the fresh feed. (This latter figure comes from the fact that the 5.0 gm. liter feed rate obtained from a charge of 2.5 liters fresh feed having a COD concentration of 20 gm. liter. Hence, the total fresh-feed COD charge was 50 gm. After 23 hours at high aeration, the undigested COD of this 2.5 liters was 2.5 × 4.5, or 11.25 gm., which amounts to 22.5% of the fresh feed.)

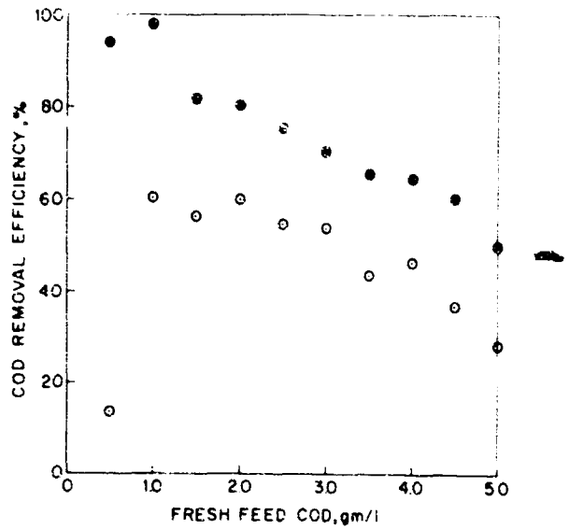
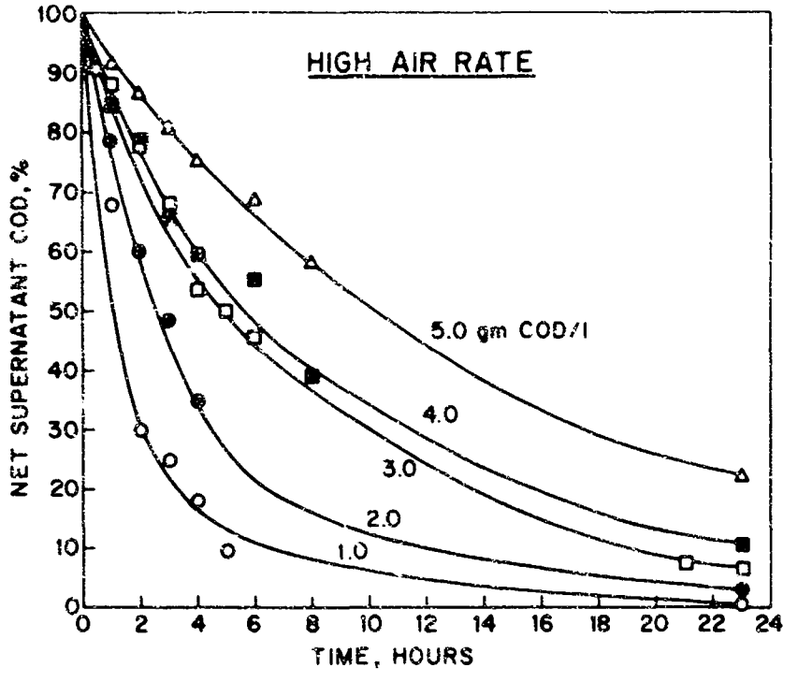


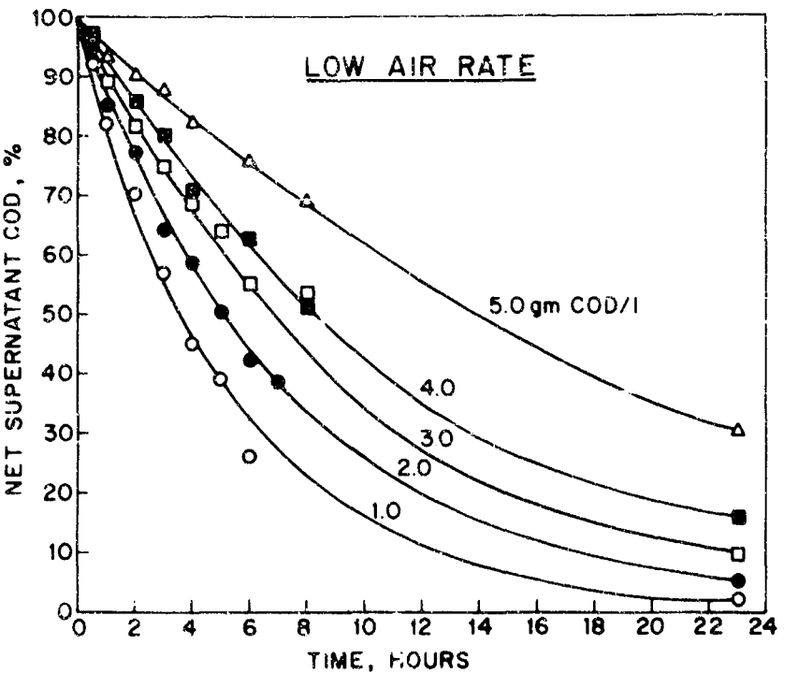
FIGURE 3

Total COD removal efficiency for a 23-hour detention culture as a function of the fresh-feed loading rate; • – high aeration, O – low aeration.

The total COD reduction efficiency is shown in figure 3 as a function of the fresh-feed rate. Here the effluent (undigested) COD was calculated as a percent of the total COD charge (fresh and residual) at the start of the reaction period. These data give a conservative picture of the efficacy of the process for waste stabilization. The COD reduction efficiency declined slowly with increased loading but remained at the 50% level or greater with high aeration even at the maximum feed rate. An improvement in reduction efficiency could be obtained with a longer detention period.

Figures 4 and 5 show the COD removal as a function of time at high and low aeration, respectively. The parameter in each figure is the concentration of fresh COD in the reactor at


HIGH AIR RATE
NET SUPERNATANT COD, %
TIME, HOURS
5.0 gm COD/l
4.0
3.0
2.0
1.0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3.0
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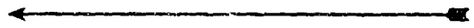

FIGURE 4

Fresh-feed COD uptake as a function of time—high aeration. Parameter is the fresh-feed loading rate.

the start of the aeration period. The ordinate is the undigested COD of the mixed liquor as a percentage of the fresh-feed charge. These data show clearly the decrease in rate of COD removal with increasing feed. At high aeration, the time required to remove 50% of the feed COD increased from 1 hour, at the 1.0 gm./liter feed level, to 10 hours at 5.0 gm./liter.

One noteworthy aspect of the data was the fact that the decay curves all followed first-order kinetics; that is, a rate law of the type:

$$\frac{dc}{dt} = -kc$$

where c is the concentration of mixed liquor COD. The first-order reaction rate constant, k, was calculated by least squares for each feed rate. With high aeration, k ranged from about 0.5/hr. at the 1.0 gm./liter feed rate to 0.07/hr. at 5.0 gm./liter. With low aeration, k varied from about 0.2/hr. to 0.05/hr. The k for each feed rate is listed in table IV.

Least squares analysis of the COD removal rate brought out the fact that at the lower feeding levels, the process was apparently limited by the availability of substrate. Exponential decay obtained through the first 8 hours of aeration, but the 23-hour COD was greater than that predicted from extrapolation of the first-order curve. Only when the feeding levels reached 3.0 gm./liter and greater did the 23-hour COD "fit" the exponential decay curve. This may have been due to the fact that at the lower feeding levels, the residual COD was too low for accurate determination. If valid, however, this finding indicates that at the lower feeding levels, COD removal was first-order by adsorption until the feed supply was nearly exhausted and then linear for the remainder of the aeration period. This phenomenon has been noted by others (3, 14). At the higher feeding levels, however, COD removal was first-order throughout. The difference in uptake rate observed between high aeration and low aeration indicates that the rate-controlling factor was probably oxygen supply.

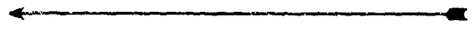

FIGURE 5

Fresh-feed COD uptake as a function of time—low aeration. Parameter is the fresh-feed loading rate.

TABLE IV

Percent of COD remaining in sludge mixture as a function of time

Time (hr.)	Feed rate (gm. COD/liter)									
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	High aeration									
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
0.50	72.5	90.6	89.5	90.0	90.1	89.5	95.5	89.5	95.0	94.9
1	53.7	67.7	70.0	78.5	86.3	88.2	84.0	84.2	90.0	91.7
2	44.8	30.0	49.4	60.0	70.0	73.5	79.8	78.5	87.7	86.4
3	17.3	25.0	27.8	48.6	60.0	68.0		65.6	76.5	80.2
4	14.5	18.0	22.1	35.0	47.0	53.2	63.7	59.5	69.5	75.2
5	8.1	9.6	15.0		41.3	50.0				
6						44.5	45.0	55.0	58.3	68.6
8							31.6	39.1	48.2	57.7
21						7.3			15.5	19.5
23	0.2	0.1	1.5	2.5	4.0	6.5	8.7	10.0	13.2	22.5
k*	0.59	0.47	0.39	0.26	0.18	0.14	0.14	0.11	0.09	0.06
	Low aeration									
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
0.50	89.9	92.1	94.1	95.0	95.2	91.8	97.2	97.1	97.0	97.1
1	78.2	82.2	85.0	85.0	85.2	89.2	90.4	90.6	91.9	92.9
2	60.1	70.2	76.0	77.0	80.0	81.5	83.5	85.2	90.4	89.6
3	51.2	57.0		64.0	70.0	74.5	77.2	79.8	88.4	87.4
4	35.6	45.0	55.2	58.5	61.8	68.	70.1	70.5	78.5	81.9
5	29.1	39.7	45.8	50.0	55.0	62.0	65.4			
6	26.3	25.9		41.8	50.0	55.2	59.9	62.0	70.5	75.4
7			35.7	38.6		53.7				
8							51.6	50.9	59.5	69.0
21										34.9
23	2.3	2.0	3.9	4.9	7.2	9.5	13.9	50.1	20.6	30.1
k*	0.23	0.21	0.15	0.14	0.12	0.09	0.08	0.08	0.06	0.05

*First-order reaction rate constant, hr.$^{-1}$

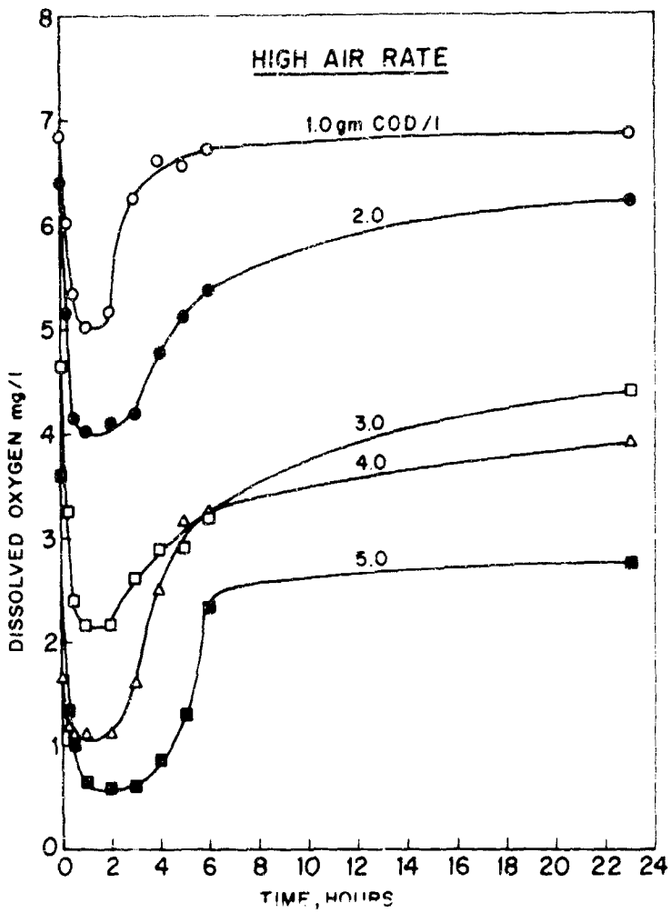

FIGURE 6

Dissolved oxygen content in the mixed liquor as a function of time—high aeration. Parameter is the fresh-feed loading rate.

Dissolved oxygen

Figures 6 and 7 give the dissolved oxygen concentration in the mixed liquor as a function of time for high and low aeration, respectively. The parameter in each figure is the fresh-feed COD charge. Of particular interest in these data was the initial change and the rate of recovery of the DO concentration. Immediately after feeding at all levels, the dissolved oxygen in the reactor dropped rapidly to a minimum value. The subsequent rate of recovery and final DO level were both feed rate and aeration dependent.

The sudden initial uptake of oxygen after feeding was presumably due to rapid oxidation of the fresh substrate. The minimum DO was reached within 1 to 2 hours and the difference between the initial and minimum DO value was in the range of 2.5 to 3.5 mg. liter, surprisingly independent of both feed rate and aeration (see table V).

The effect of increasing feed on the rate of DO recovery was more pronounced in the low-aeration curves. The recovery rate dropped with increasing feed as did the final (23-hour) DO level. At low aeration the final DO level

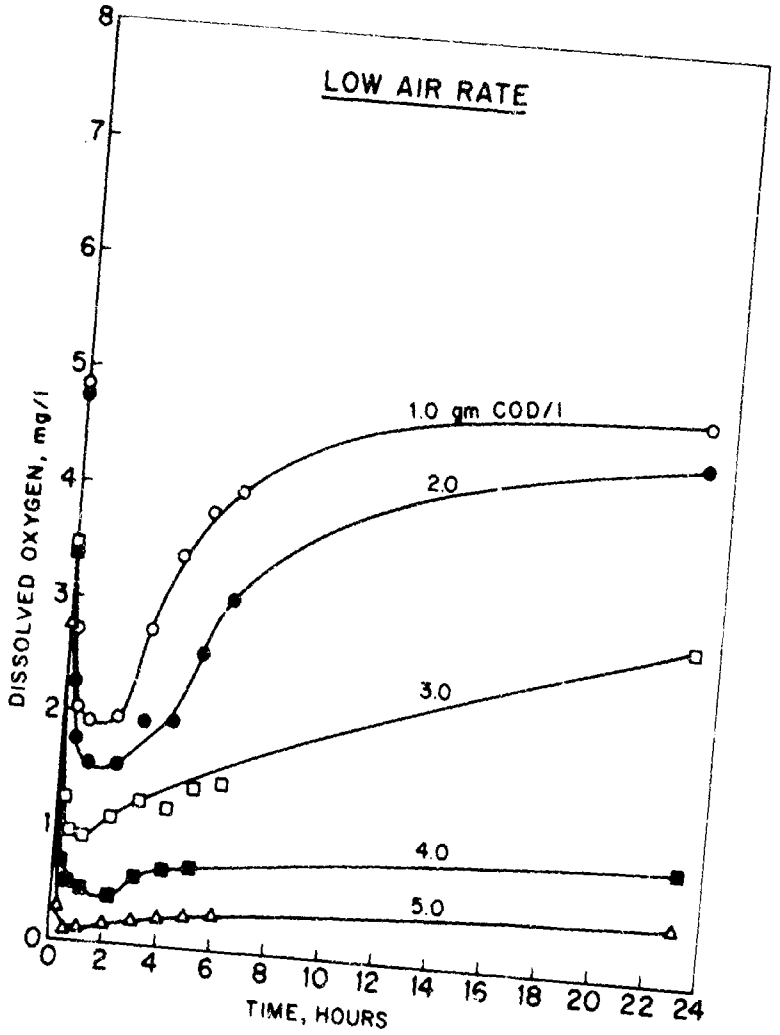

FIGURE 7

Dissolved oxygen content in the mixed liquor as a function of time—low aeration. Parameter is the fresh-feed loading rate.

was 90% to 100% of the initial, up to a feeding rate of 3.0 gm. liter, thereafter dropping steadily to less than 20% at the highest feed rate. At high aeration, however, the final DO level was 90% to 100% of the initial at all feeding levels except the highest.

Color

As the run progressed, the color of the clarified effluent went from essentially clear to that resembling coffee, at the high feed rates. This color has been noted by others and was identified by Emanuel (7) as a brown pigment, hestianic acid. Spectrographic analysis of the colored effluent revealed that although a broad adsorption band was observed in the 200 to 300 mμ range, no sharp adsorption peak was detected in the visible or ultraviolet band that could be used to quantify the pigment. The presence of this coloration may be important when the sludge process is coupled to an algal photosynthetic exchanger. In thin-paneled algal culture vessels, the pigment will absorb light, thus reducing the available energy for photosynthesis. An ultrafiltration system is currently under development for removal of this pigment and other organic materials from activated sludge process effluent (10).

TABLE V

Dissolved oxygen concentration of sludge mixture as a function of time

Time, hr.	Feed rate (gm. COD/liter)									
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	High aeration									
0	6.9	6.8	6.5	6.4	5.7	4.7	4.6	4.0	3.8	3.6
0.25	6.6	6.0	5.4	5.2	4.2	3.2	2.6	1.7	2.2	1.3
0.50	6.0	5.4	5.0	4.2	3.5	2.4	1.9	1.2	1.2	1.1
1	5.3	5.0	4.9	4.0	3.0	2.2	1.8	1.1	0.9	0.7
2	5.4	5.2	4.9	4.1	2.9	2.2	1.6	1.1	0.9	0.6
3	5.9	6.3	5.2	4.2	3.0	2.6	1.8	1.6	0.8	0.6
4	6.4	6.6	5.3	4.8	3.5	2.9	1.7	2.5	1.1	0.9
5	6.6	6.6	6.0	5.1	4.1	2.9	1.9	3.1	2.0	1.3
6	6.7	6.7	6.3	5.4	4.7	3.2	2.0	3.2	2.8	2.3
23	6.9	6.9	6.6	6.2	5.7	4.4	4.3	3.9	3.8	2.7
	Low aeration									
0	4.8	4.8	5.1	4.9	4.8	3.5	3.5	3.4	3.5	2.7
0.25	2.5	2.7	2.3	2.2	2.3	1.3	1.0	0.7	0.7	0.3
0.50	1.9	2.0	1.7	1.8	1.6	1.0	0.8	0.5	0.4	0.1
1	1.4	1.9	1.6	1.5	1.4	0.9	0.7	0.4	0.5	0.1
2	2.0	2.0	1.8	1.6	1.5	1.1	0.8	0.4	0.3	0.1
3	2.7	2.7	2.6	1.9	2.4	1.2	0.9	0.6	0.5	0.2
4	3.3	3.4	2.5	2.0	2.8	1.2	1.1	0.7	0.5	0.2
5	3.9	3.7	3.0	2.6	3.2	1.4	1.1	0.7	0.5	0.3
6		4.0		3.1	3.3	1.5	1.3		0.8	0.3
23	5.8	4.8	4.7	4.5	4.9	2.9	1.4	1.0	1.0	0.5

Nitrogen and phosphorus quality

Table III shows the quality and concentration of the nitrogen and phosphorus in the clarified effluent for the various conditions of the run. As was expected, the quantity of both these substances in the effluent increased with the feeding level. Of some concern was the observed shift in nitrogen quality from nitrate to nitrite and ammonia-nitrogen. With high aeration and low feed rate, all the nitrogen apppeared as nitrate, signifying complete oxidation. As the feeding level increased and particularly at low aeration, the nitrogen appeared predominantly as nitrite and ammonia indicating relatively incomplete oxidation. This finding may be of importance when sludge effluent is used for algal substrate. Nitrate and ammonia-nitrogen can be utilized by many species of algae but nitrite at concentrations higher than 0.001 M (46 p.p.m.) may be inhibitory to algal growth (9). Hence, the maintenance of sufficient aeration appears necessary to insure complete oxidation of the fixed nitrogen.

IV. DISCUSSION

The results of this study indicate that a batch-fed, or intermittently fed, activated sludge culture can be acclimated to handle human excreta with little dilution. At loading levels of 5 gm. COD liter of culture, nearly 80% of the COD can be removed in 23 hours of processing. It is probable that the COD removal capacity can be increased by a longer detention period or better definition of the oxygen supply requirements. The aeration rates we used were

calculated to be excessive while the results indicate that at the 5.0 gm. COD liter feeding level, dissolved oxygen was a limiting factor.

The activated sludge unit employed in this work proved to be an adequate laboratory tool. A possible improvement on the design would be to lengthen the reactor cone to about 1 m. and reduce the diameter accordingly to maintain the desired volume. This modification would improve mixing and allow longer contact time for aeration. While the energy requirements for forced aeration might be greater, the longer gas-liquid contacting time should reduce the total air supply requirement.

A more complete definition of waste treatment in space may require a study of wastes from individuals on a diet of liquid or compressed low-bulk foods and in a restricted environment. Undoubtedly, a low-bulk diet would result in smaller fecal quantities which would, in turn, reduce the available carbon source for microorganisms. However, this should only reduce the total amount of waste to be processed. According to Slonim and Mohlman (12) the type of low-bulk diet employed has little effect on the quality of fecal or urinary excretions.

The work reported here was a necessary preliminary step to a continuous feeding study. The adaptability of activated sludge to concentrated waste feed was demonstrated and the effects of dissolved oxygen on culture performance and effluent quality were determined. A continuous feed system offers the advantage of steady-state operation at a more rapid oxidation rate than can be obtained in a batch-fed system. A continuous feed regimen should eliminate the rapid decrease in dissolved oxygen observed with bulk loading and permit better utilization of aeration capacity. In addition, a steady-state continuous process can be systematically optimized to produce effluent of higher quality.

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) USAF School of Aerospace Medicine Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b GROUP

3 REPORT TITLE

BATCH-FEEDING STUDIES ON HIGH-SOLIDS ACTIVATED SLUDGE FOR TREATING CONCENTRATED HUMAN WASTE

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Jan. - June 1967

5 AUTHOR(S) (First name, middle initial, last name)

Michael J. Ryan, Captain, USAF, BSC
Richard L. Miller

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
September 1968	15	14
8a CONTRACT OR GRANT NO	9a ORIGINATOR'S REPORT NUMBER(S)	
b PROJECT NO	SAM-TR-68-108	
c Task No. 793001	9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d		

10 DISTRIBUTION STATEMENT

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11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY
	USAF School of Aerospace Medicine Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas

13 ABSTRACT

As part of a continuing Air Force research effort toward the development of a biologic waste management system for closed environments, studies were conducted on a miniaturized activated sludge process for treating concentrated human wastes. During a 40-day continuous run, a prototype sludge reactor was fed batchwise (daily) with an increasing quantity of mixed human waste. Removal of chemical oxygen demand (COD) and the quality of the clarified process effluent were monitored as functions of time and the feeding rate. Results showed that the activated sludge culture could be acclimated to handle highly concentrated human excreta with little dilution. At a loading rate of 5.0 gm. COD/liter of culture, approximately 80% of the feed COD was removed after 24 hours of processing. Both the capacity for COD removal and the quality of the process effluent were found to be strong functions of the air supply rate. Recommendations were made regarding the use of a continuous feed system for better optimization of the upgrade rate.

DD FORM NO. 1473

Unclassified

Security Classification